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Options and Challenges for OD Environment Remediation

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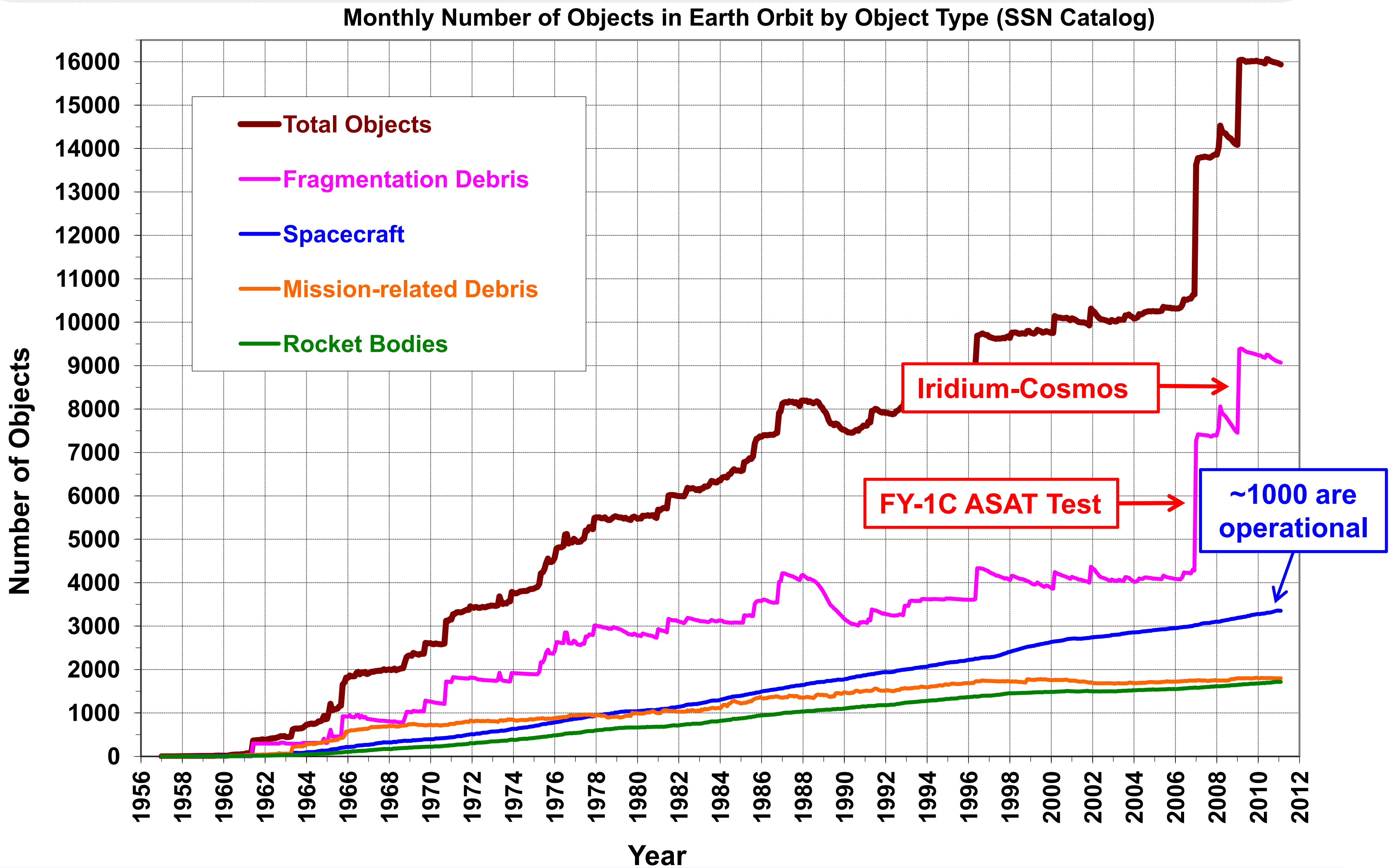
Outline

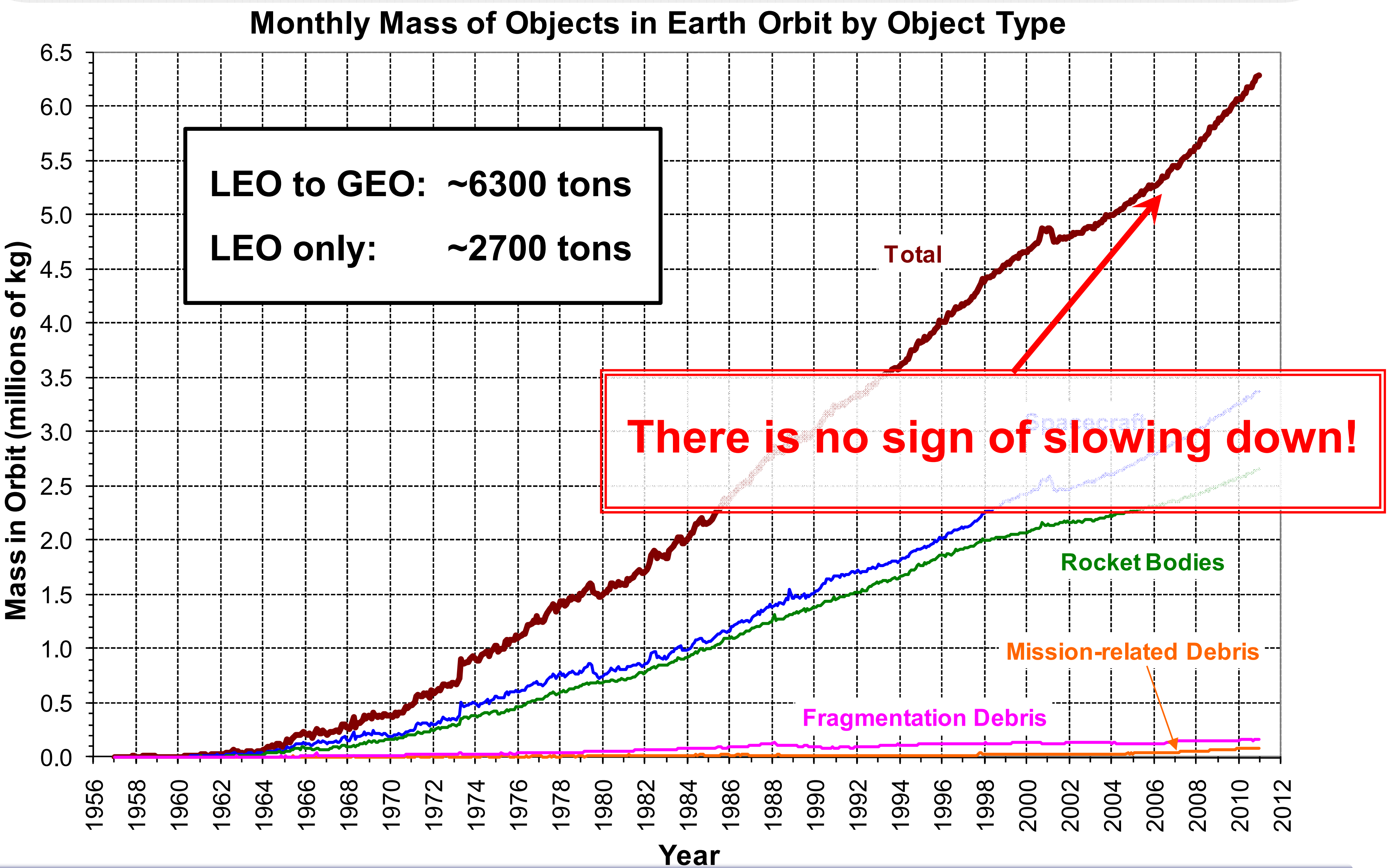
- **Key Information for the OD Environment**
- **Projected Growth of the Future OD Population**
- **Preserving the Environment with Active Debris Removal (ADR)**
- **A Grand Challenge for the 21st Century**
- **Recent ADR Activities at the International Level**

Key Information for the Orbital Debris Environment

Growth of the Historical Catalog Populations

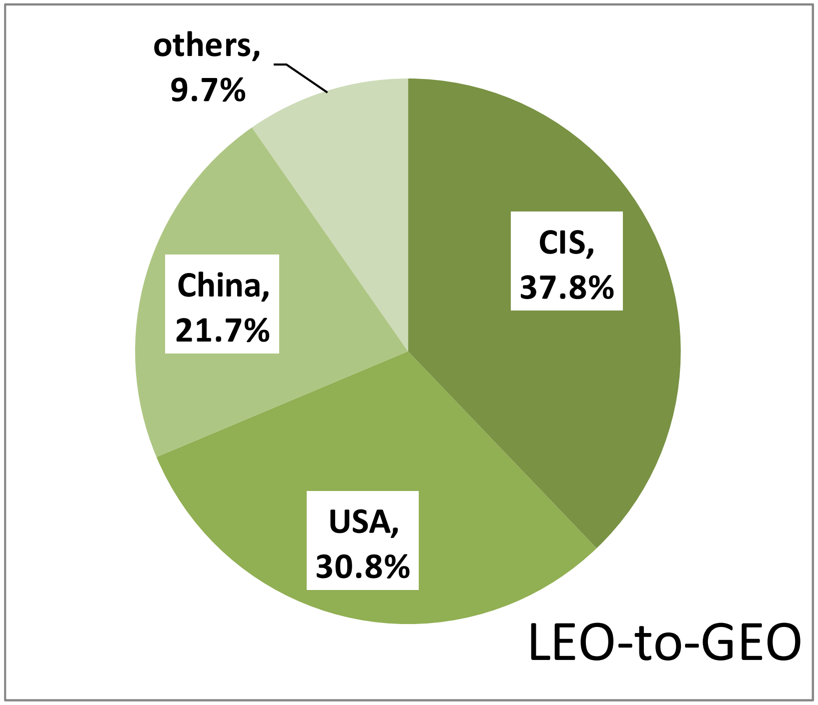


Mass in Orbit

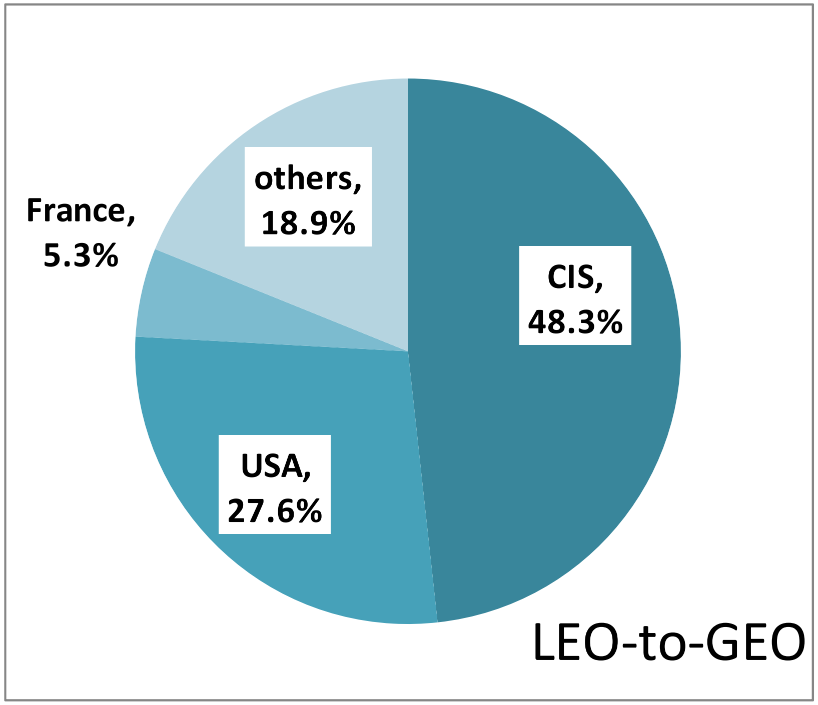


Sources of the Catalog Population – All

Number Breakdown



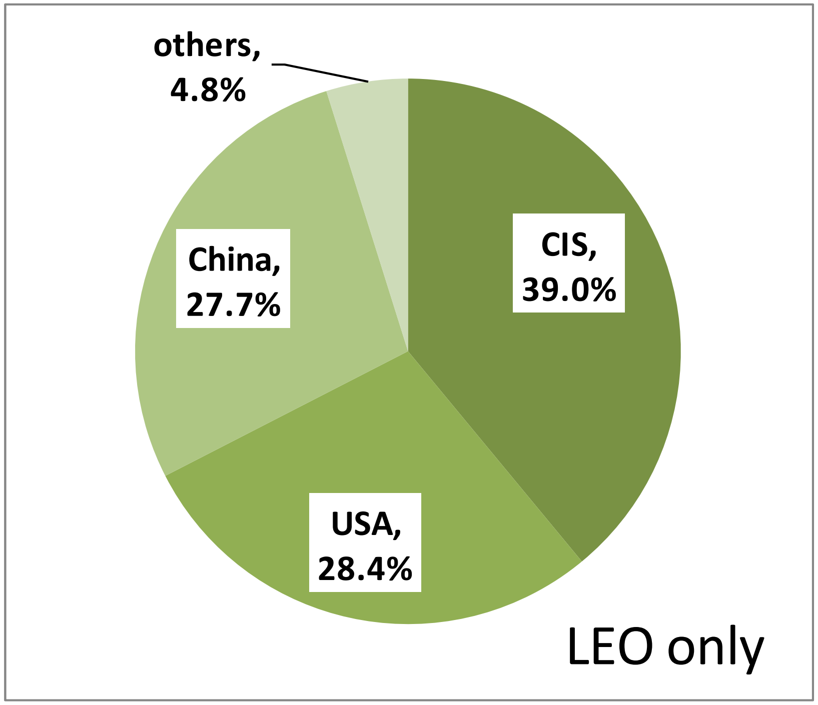
Mass Breakdown



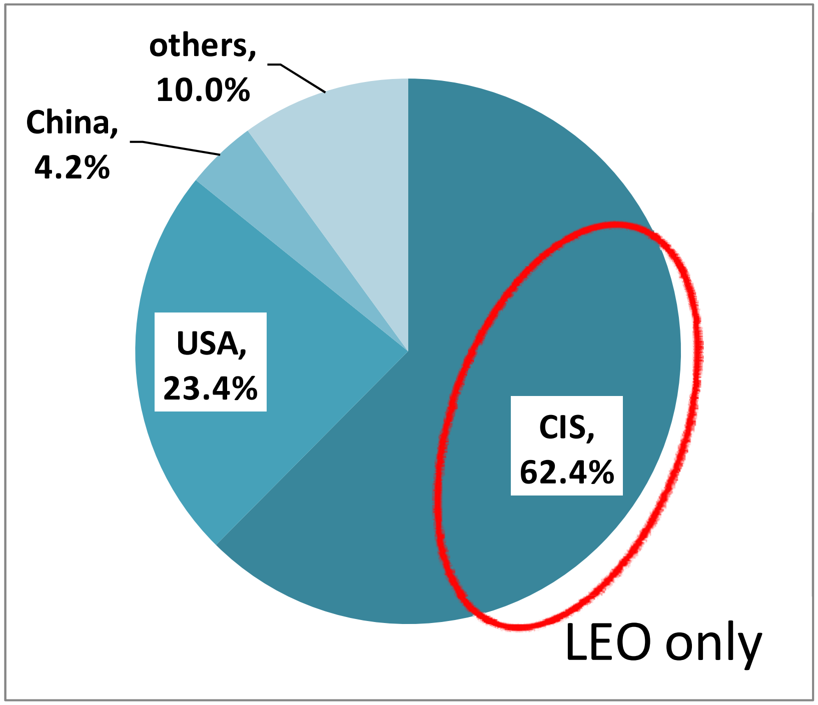
CIS = Former Soviet Republics

Sources of the Catalog Population – LEO Only

Number Breakdown

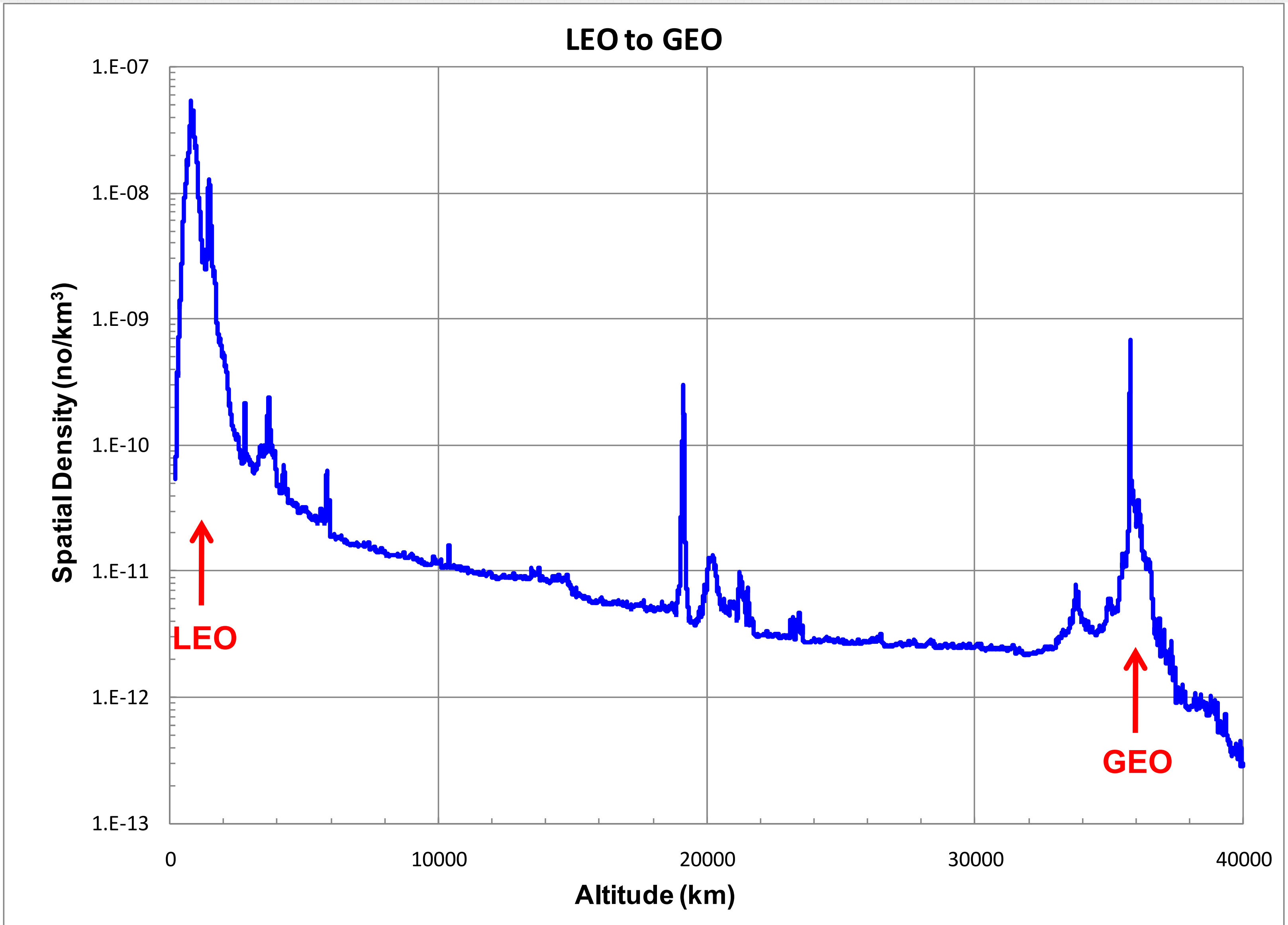


Mass Breakdown

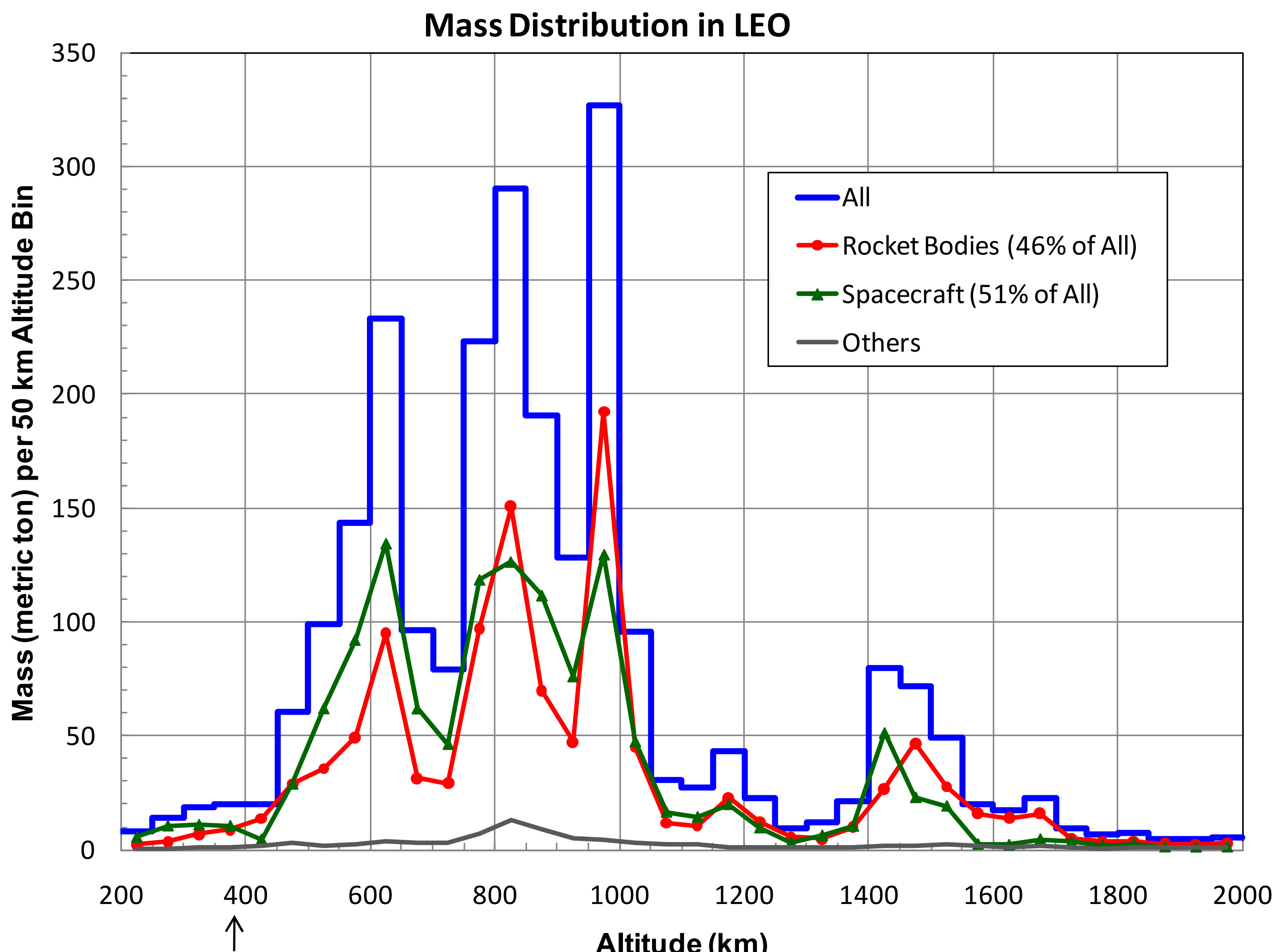


CIS = Former Soviet Republics

Spatial Density of the Catalog Population (1/2)



Mass Distribution in LEO



ISS (~400 tons) not included

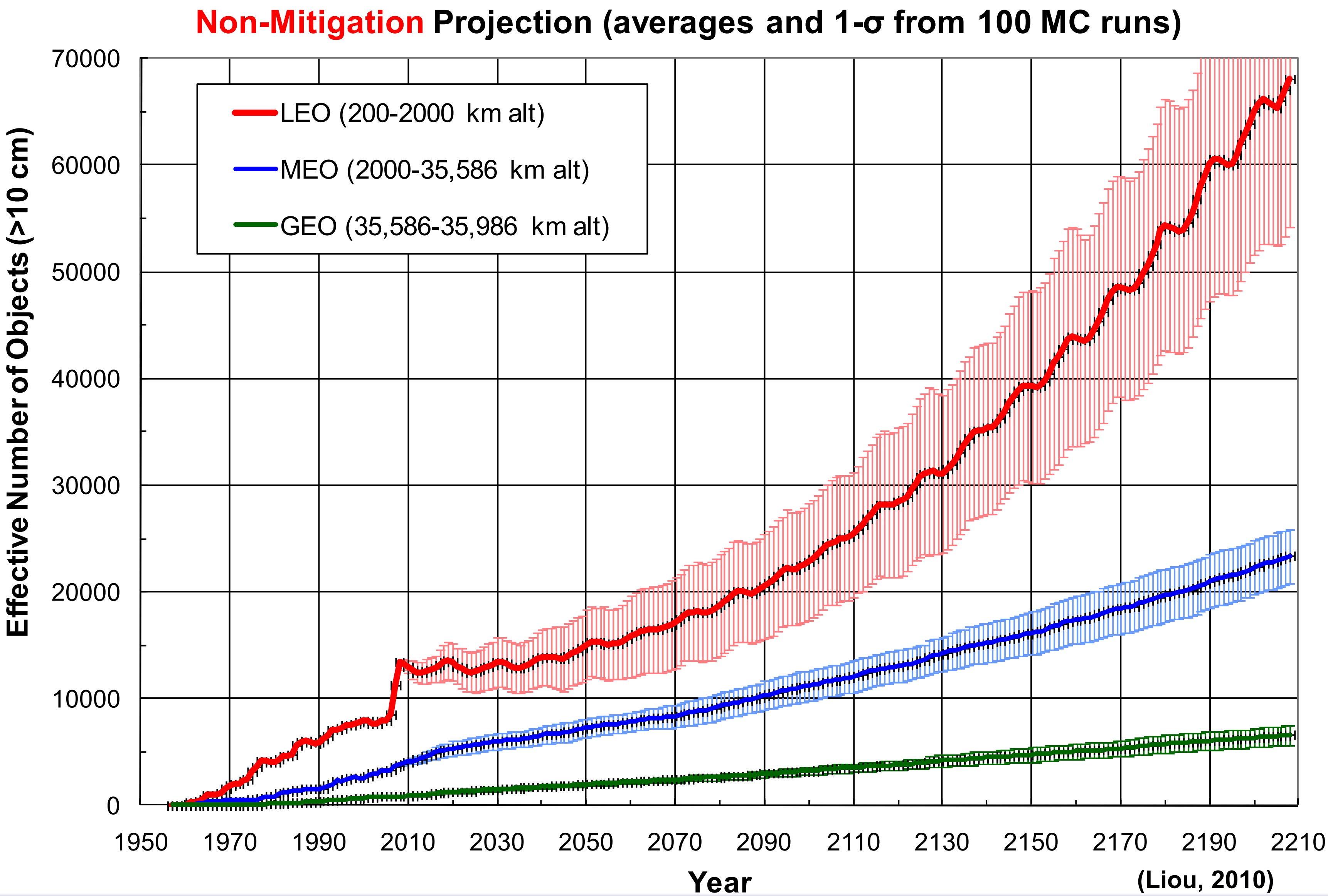
Projected Growth of the Future Debris Environment

(Worst case, best case, and “realistic” scenarios)

Debris Environment Modeling

- **All environment simulations are based on LEGEND (a LEO-to-GEO Environment Debris model)**
  - LEGEND is the high fidelity orbital debris evolutionary model developed by the NASA Orbital Debris Program Office
  - LEGEND simulates objects individually, incorporates major perturbations in orbit propagation, and includes major source and sink mechanisms (launches, breakups, decays)
  - Ten peer-reviewed journal papers have been published on LEGEND and its applications since 2004
  - The following discussions will focus on ≥10 cm objects and limit the future projection to 200 years

Future Projection – The Worst Case Scenario
(Regular Satellite Launches, but No Mitigation Measures)



(Liou, 2010)

Assessments of the Non-Mitigation Projection

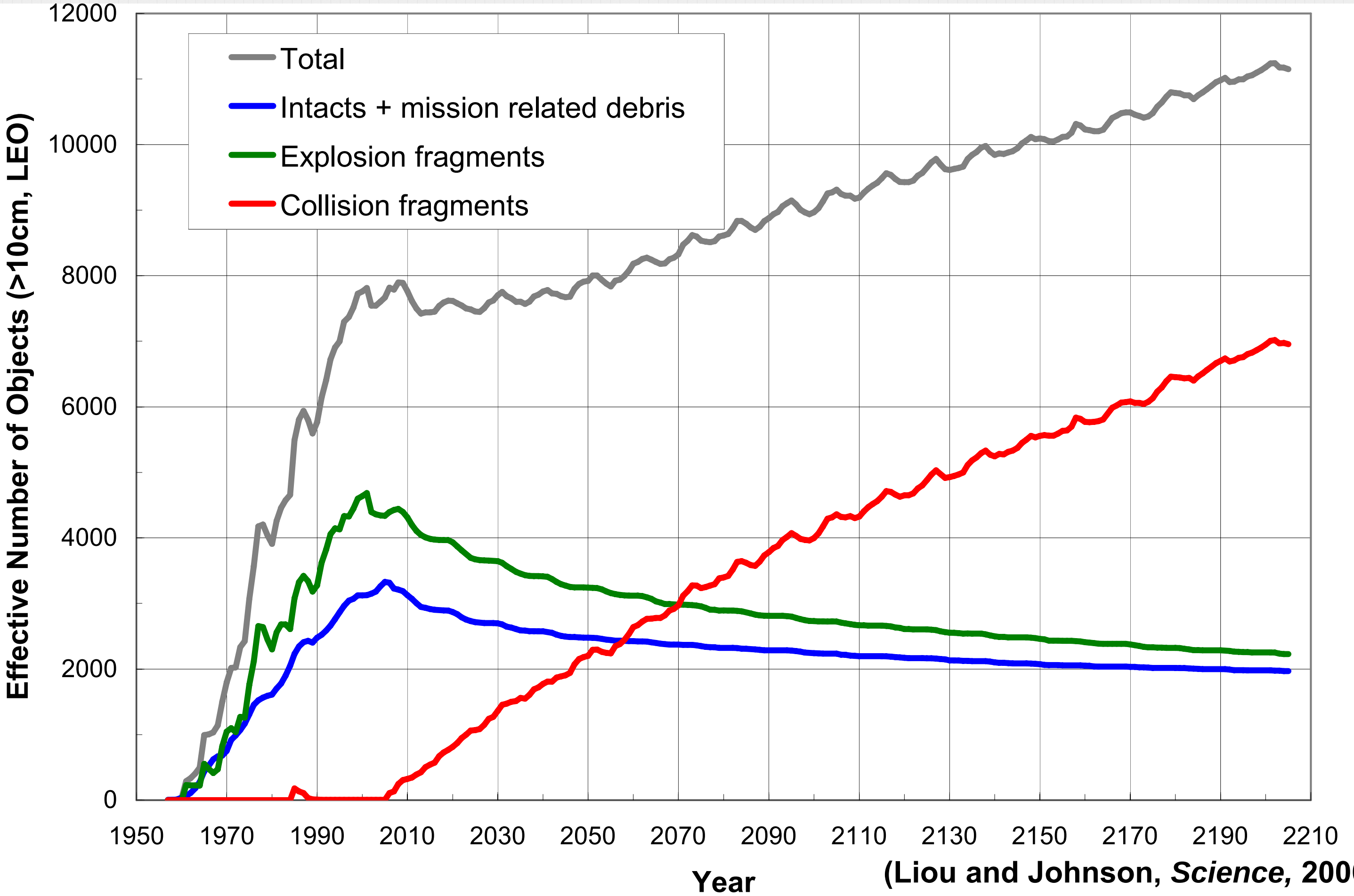
- **LEO: the non-mitigation scenario predicts the debris population (≥10 cm objects) will have a rapid non-linear increase in the next 200 years**
  - This is a well-known trend (the “Kessler Syndrome”) that was the motivation for developing the currently-adopted mitigation measures (*e.g.*, the 25-yr rule) in the last 15 years

- **MEO and GEO: the non-mitigation scenario predicts a moderate population growth**
  - Only a few accidental collisions between ≥10 cm objects are predicted in the next 200 years
  - The currently-adopted mitigation measures (including EOL maneuvers in GEO) will further limit the population growth
  - Environment remediation is not urgent in MEO and GEO

Will the Commonly-Adopted Mitigation* Measures Stabilize the Future LEO Environment?

***Mitigation = Limit the generation of new/long-lived debris (NPR 8715.6A, NASA-STD-8719.14, USG OD Mitigation Standard Practices, UN Debris Mitigation Guidelines, *etc*.)**

Future Projection – The Best Case Scenario
(No New Launches Beyond 1/1/2006)



(Liou and Johnson, *Science*, 2006)

- **Collision fragments replace other decaying debris through the next 50 years, keeping the total population approximately constant**
- **Beyond 2055, the rate of decaying debris decreases, leading to a net increase in the overall satellite population due to collisions**

Assessments of the No-New-Launches Scenario

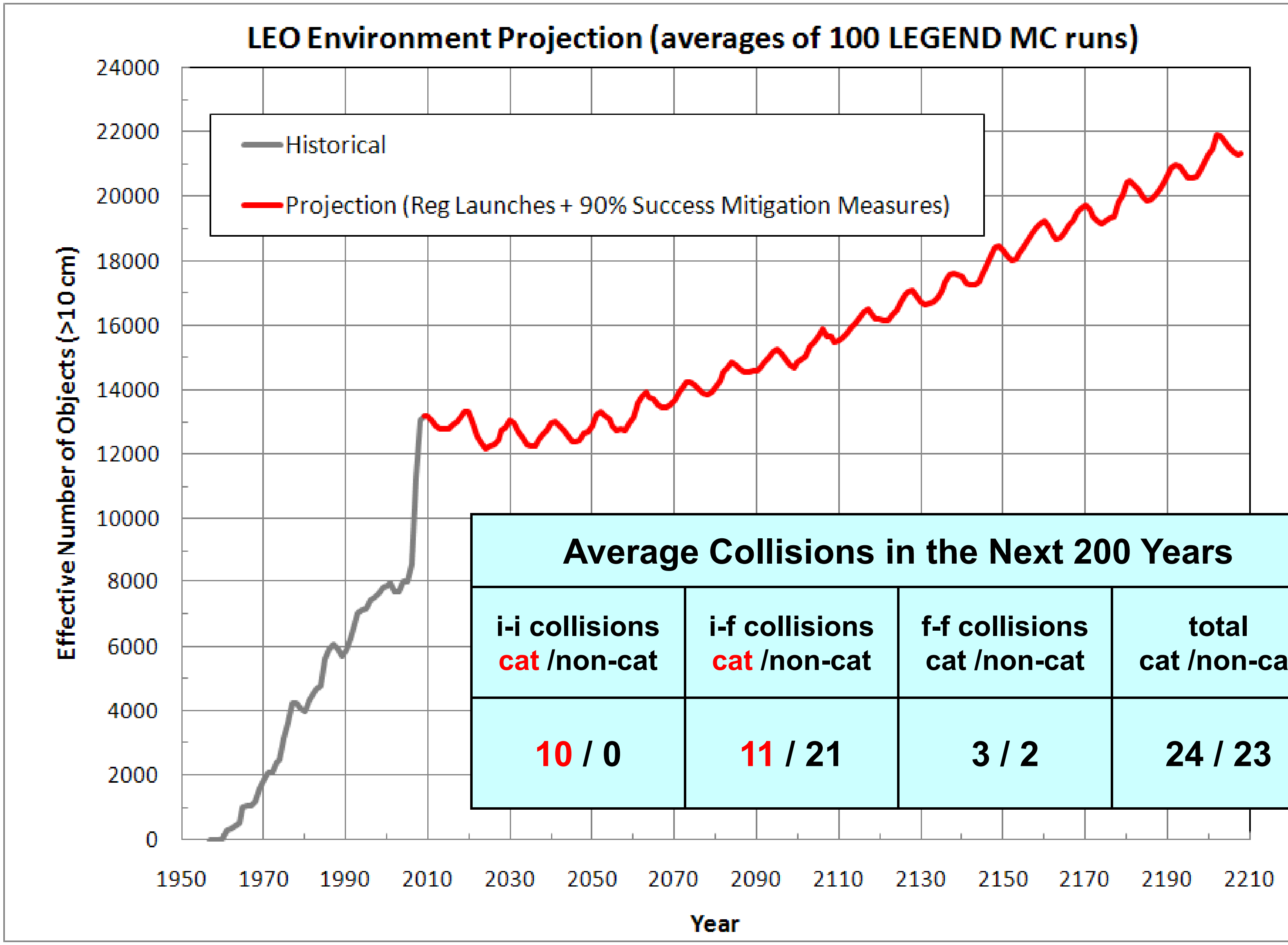
- **In reality, the situation will be worse than the "no new launches" scenario as**
  - Satellite launches will continue
  - Major unexpected breakups may continue to occur (*e.g.*, Fengyun-1C)
- **Postmission disposal (such as a 25-year decay rule) will help, but will be insufficient to prevent the self-generating phenomenon from happening**
- **To preserve the near-Earth space for future generations, ADR must be considered**

Conclusions of the 2006 Paper

- **"The current debris population in the LEO region has reached the point where the environment is unstable and collisions will become the most dominant debris-generating mechanism in the future."**
- **"Only remediation of the near-Earth environment – the removal of existing large objects from orbit – can prevent future problems for research in and commercialization of space."**

- Liou and Johnson, ***Science***, 20 January 2006

Environment Projection With Mitigation Measures



Average Collisions in the Next 200 Years			
i-i collisions cat /non-cat	i-f collisions cat /non-cat	f-f collisions cat /non-cat	total cat /non-cat
10 / 0	11 / 21	3 / 2	24 / 23

International Consensus

- **The LEO environment instability issue is under investigation by the Inter-Agency Space Debris Coordination Committee (IADC) members**
- **An official "Stability of the Future LEO Environment" comparison study was initiated in 2009**
  - Six participating members: NASA (lead), ASI, ESA, ISRO, JAXA, and UKSA
  - Results from the six different models are consistent with one another, *i.e.*, even with a good implementation of the commonly-adopted mitigation measures, the LEO debris population is expected to increase in the next 200 years
  - Study summary was presented at the April 2011 IADC meeting

Inter–Agency Space Debris Coordination Committee

Preserving the Environment with Active Debris Removal (ADR*)

***ADR = Removing debris beyond guidelines of current mitigation measures**

Key Questions for ADR

- **Where is the most critical region for ADR?**
- **What are the mission objectives?**
- **What objects should be removed first?**
  - The debris environment is very dynamic. Breakups of large intacts generate small debris, small debris decay over time,…
- **What are the benefits to the environment?**
- **How to do it?**

→ **The answers will drive the top-level requirements, the necessary technology development, and the implementation of ADR operations**

How to Define Mission Success?

- **Mission objectives guide the removal target selection criteria and the execution of ADR**
- **Common objectives**
  - Follow practical/mission constraints (in altitude, inclination, class, size, *etc*.)
  - Maximize benefit-to-cost ratio
- **Specific objectives**
  - Control population growth (small & large debris)
  - Limit collision activities
  - Mitigate mission-ending risks (not necessarily catastrophic destruction) to operational payloads
  - Mitigate risks to human space activities
  - And so on

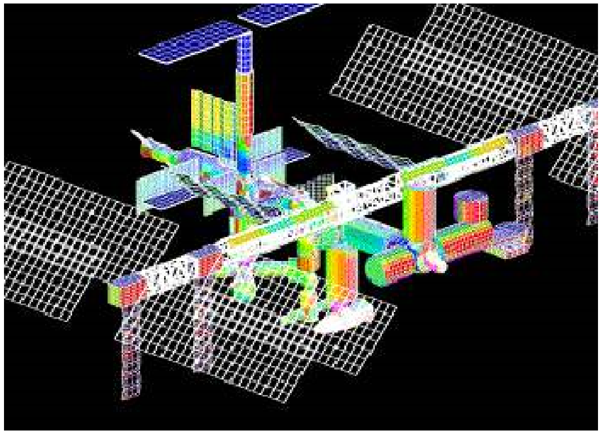
Target large & massive intacts

Target small debris

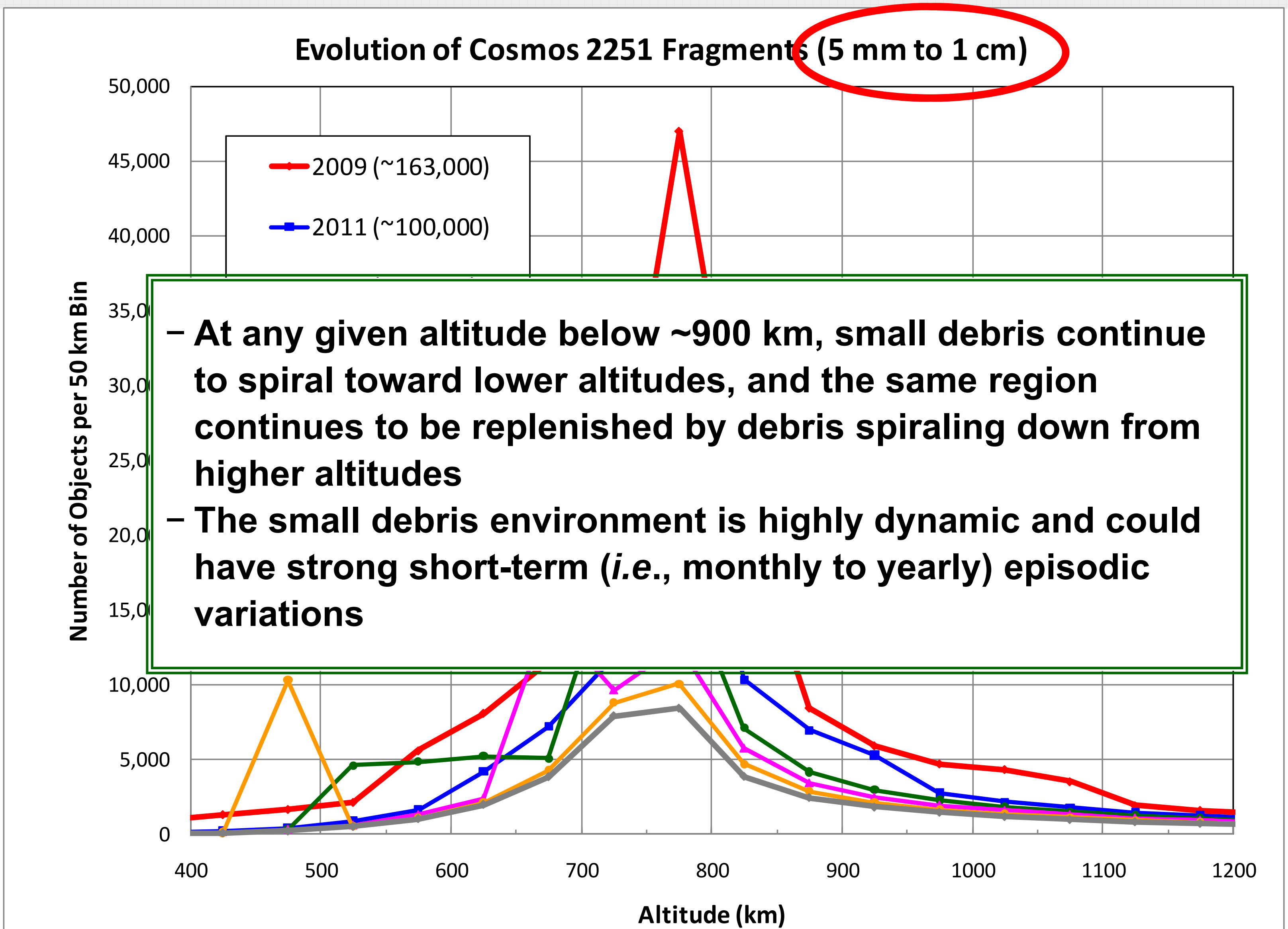
Target Small Debris

One Example: Risks From Small Debris

- **The U.S. segments of the ISS are protected against orbital debris about 1.4 cm and smaller**
  - "Currently," the number of objects between 1.5 cm and 10 cm, with orbits crossing that of the ISS, is approximately 1200
    - **~800 of them are between 1.5 cm and 3 cm**
  - To reduce 50% of the ISS-crossing orbital debris in this size range (1.5 cm to 3 cm) will require, for example, a debris collector/remover with an area-time product of ~1000 km^2 year



Small Debris Environment Is Highly Dynamic



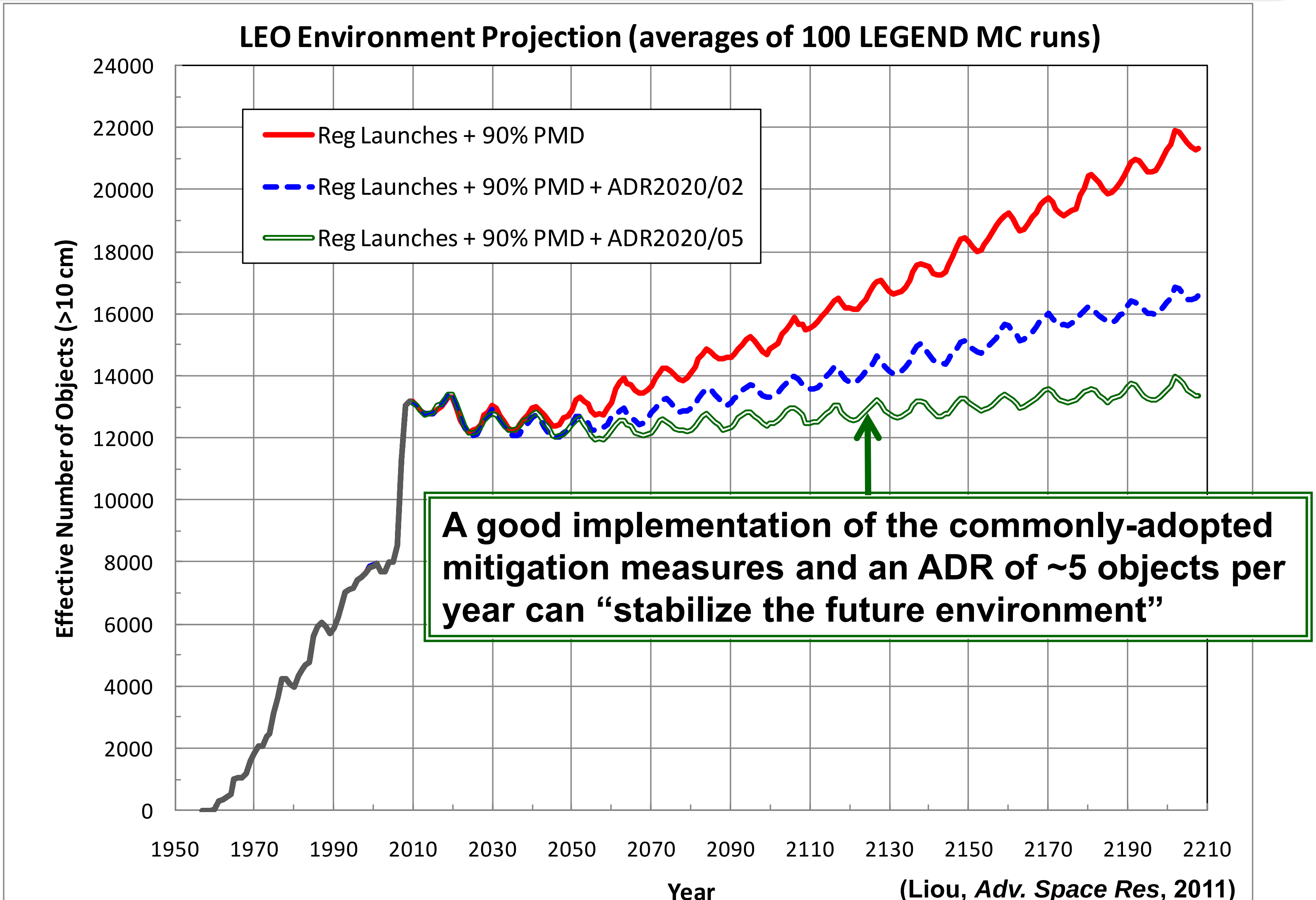
- At any given altitude below ~900 km, small debris continue to spiral toward lower altitudes, and the same region continues to be replenished by debris spiraling down from higher altitudes
- The small debris environment is highly dynamic and could have strong short-term (*i.e.*, monthly to yearly) episodic variations

Target Large Debris

Targeting the Root Cause of the Problem

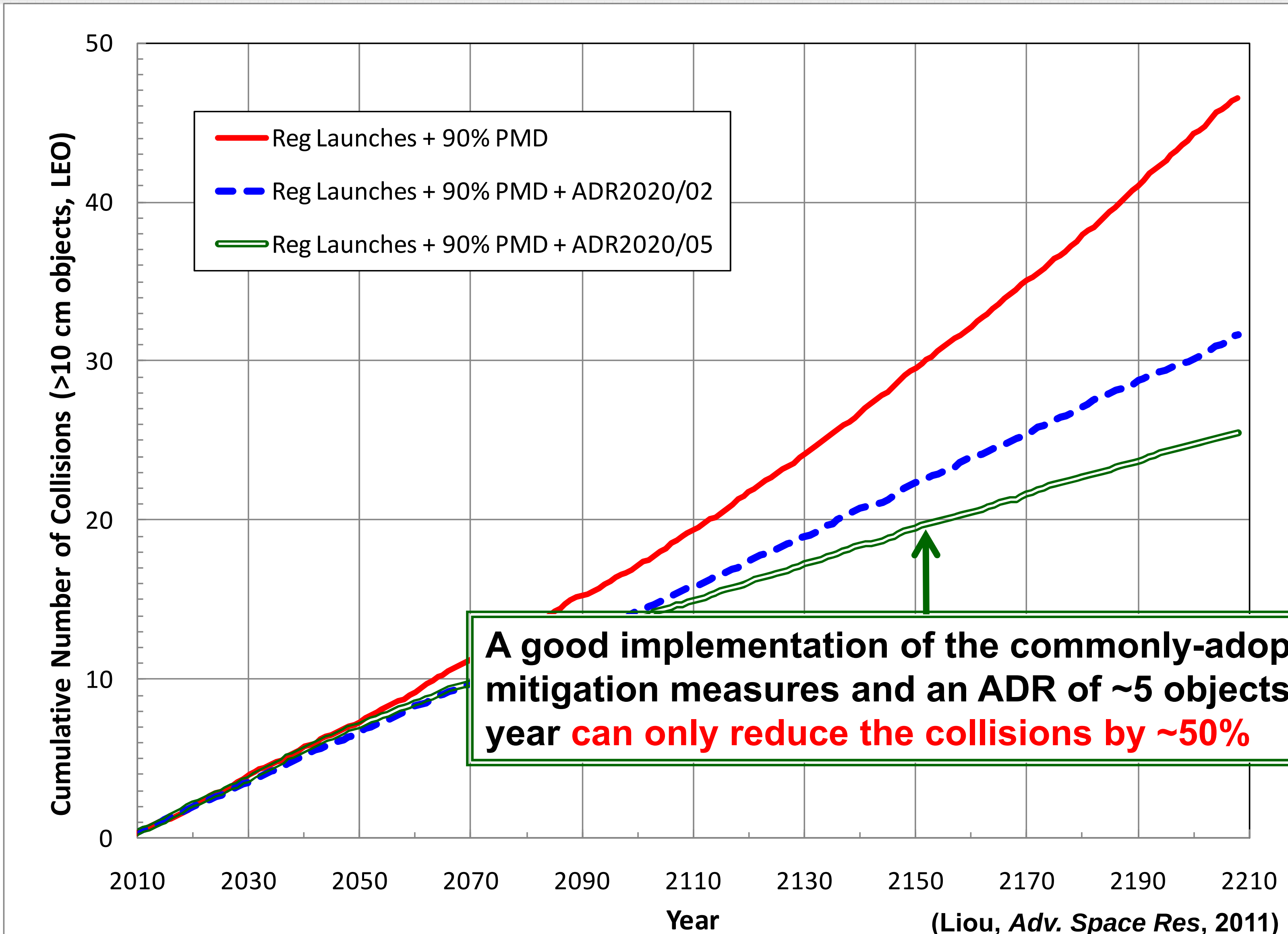
- **A 2008-2009 NASA study shows that the two key elements to stabilize the future LEO environment (in the next 200 years) are**
  - A good implementation of the commonly-adopted mitigation measures (passivation, 25-year rule, avoid intentional destruction, *etc.)*
  - An active debris removal of about five objects per year
    - **These are objects with the highest [M × P_{coll}]**
    - **Many (but not all) of the potential targets in the current environment are spent Russian SL upper stages**
      - **Masses: 1.4 to 8.9 tons**
      - **Dimensions: 2 to 4 m in diameter, 6 to 12 m in length**
      - **Altitudes: ~600 to ~1000 km regions**
      - **Inclinations: ~7 well-defined bands**

Controlling Debris Growth with ADR



(Liou, *Adv. Space Res*, 2011)

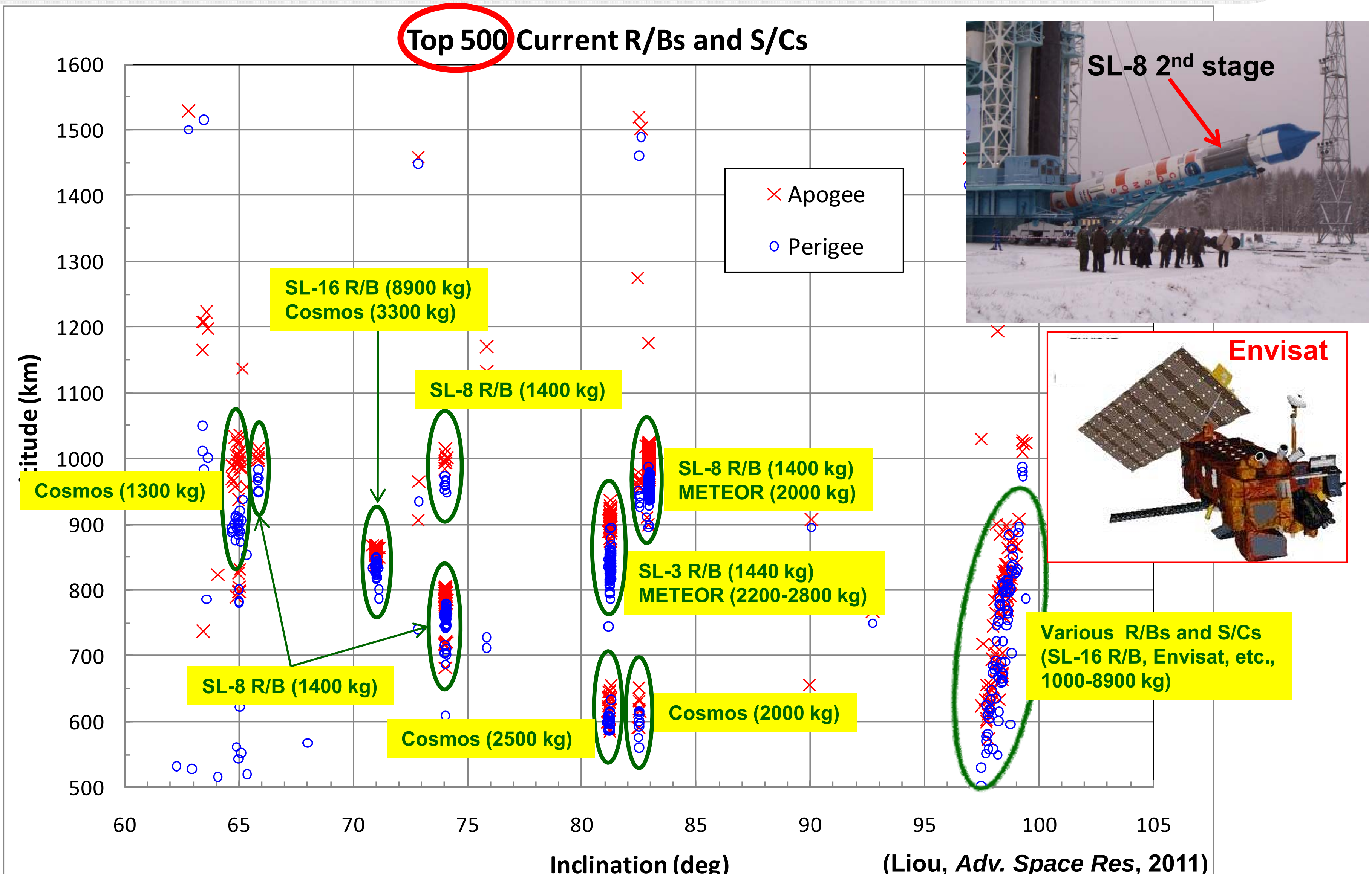
Projected Collision Activities in LEO



A good implementation of the commonly-adopted mitigation measures and an ADR of ~5 objects per year can only reduce the collisions by ~50%

(Liou, *Adv. Space Res*, 2011)

Potential Active Debris Removal Targets



(Liou, *Adv. Space Res*, 2011)

National Space Policy of the United States of America (28 June 2010)

- **Orbital debris is mentioned on 4 different pages for a total of 10 times in this 14-page policy document**
- **On page 7:**

Preserving the Space Environment and the Responsible Use of Space

Preserve the Space Environment. For the purposes of minimizing debris and preserving the space environment for the responsible, peaceful, and safe use of all users, the United States shall:

- …
- Pursue research and development of technologies and techniques, through the Administrator of the National Aeronautics and Space Administration (NASA) and the Secretary of Defense, to mitigate and remove on-orbit debris, reduce hazards, and increase understanding of the current and future debris environment; and
- …

Challenges for ADR Operations

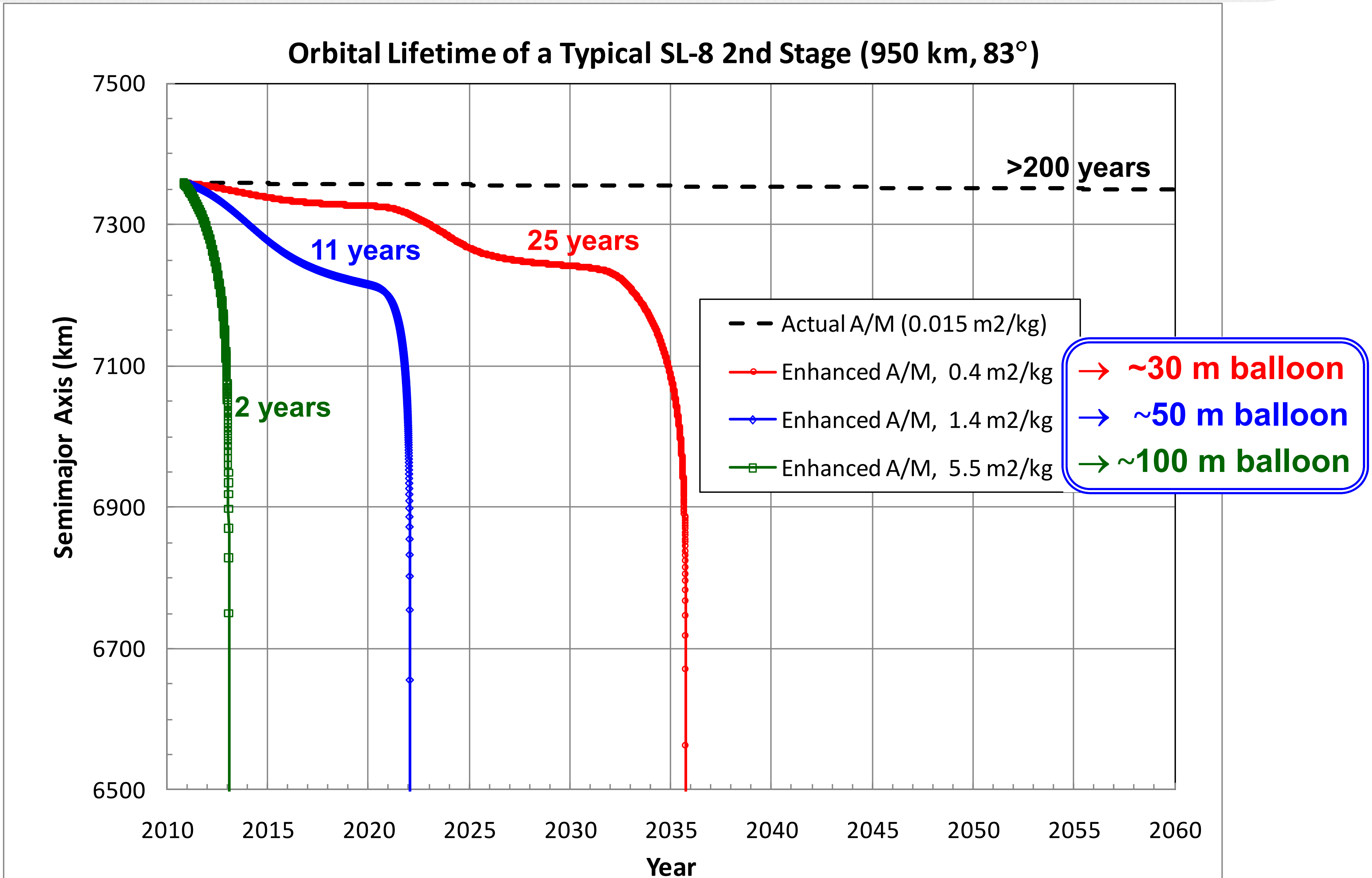
Operations	Technology Challenges
Launch	Single-object removal per launch is not feasible from cost perspective
Propulsion	Solid, liquid, tether, plasma, laser, drag-enhancement devices, others?
Precision Tracking	Ground or space-based
GN&C and Rendezvous	Autonomous, non-cooperative targets
Stabilization (of the tumbling targets)	Physical or non-physical (how)
Capture or Attachment	Physical (where, how) or non-physical (how), do no harm
Deorbit or Graveyard Orbit	When, where, reentry ground risks

- **Other requirements:**
  - Affordable cost
  - Repeatability of the removal system (in space)
  - Target R/Bs first?

The First Step

- **Identify top-level requirements for an end-to-end ADR operation**
  - Launch, propulsion, precision tracking, GN&C, rendezvous, stabilization, capture/attachment, deorbit, ground support, etc
  - Define stakeholders and their expectations to drive the development of a concept of operations
- **Conduct mission design analyses and establish a feasible forward plan**
  - Identify TRLs of existing technologies
  - Evaluate pros and cons of different technologies (*e.g.*, space tugs vs. drag-enhancement devices)
  - Identify technology gaps (*e.g.*, ways to stabilize a massive, non-cooperative, fast spinning/tumbling target)
  - Perform trade studies (*e.g.*, physical vs. non-physical capture; deorbit vs. graveyard orbit)

An Example – Deorbit With Drag-Enhancement Devices



Recent ADR Activities at the International Level

NASA-DARPA International Conference on Orbital Debris Removal (Dec. 2009)

- **The 2.5-day conference included 10 sessions**
  - Understanding the Problem; Solution Framework; Legal & Economic; Operational Concepts; Using Environmental Forces; Capturing Objects; Orbital Transfer; Technical Requirements; In Situ vs. Remote Solutions; Laser Systems
  - Had 275 participants from 10 countries; 52 presentations plus 4 keynote speeches
- **The conference reflected a growing concern for the future debris environment**
- **It represented the first joint effort for different communities to explore the issues and challenges of active debris removal**

Registration

Register on-line prior to November 23, 2009 at https://www.enstg.com/signup. Enter code: INT11415

A $300 (USD) conference fee applies. Registration includes:

- Attendance at the two-and-a-half day conference
- Continental breakfast each morning
- Luncheons Tuesday & Wednesday

Hotel reservations can be made at the conference location while rooms last:

Westfields Marriott
14750 Conference Center Drive
Chantilly, VA 20151
Phone: 800-635-5666 (Reference: Orbital Debris Removal)
Or online at: http://www.westfieldsmarriott.com
Group code: CODCODA

Room rate for conference attendees is $149 (USD).

International Conference on Orbital Debris Removal
December 8-10, 2009

NASA
Chantilly, Virginia
USA
DARPA

Call for Presentations

Attendees wishing to present an appropriate technical or scholarly briefing consistent with the conference topics may submit a 250 word abstract in English via e-mail to the selection committee at: orbitaldebrisconference@darpa.mil. Submissions must be received by October 30, 2009, and include a title and the author's name and affiliation. If your abstract is selected for presentation you will be asked to submit a full presentation prior to November 30, 2009.

Numerous fora have been held in the past to discuss issues related to orbital debris. However, this first of its kind conference, co-hosted by the National Aeronautics and Space Administration (NASA) and the Defense Advanced Research Projects Agency (DARPA), will bring government and industry together to address the issues and challenges involved with removing manmade orbital debris from Earth orbit.

Other Major Events (1/2)

- **International Science and Technology Center (ISTC) Space Debris Mitigation Workshop**
  - A two-day workshop in Moscow in April 2010
  - An international group of experts (IGOE) panel was formed to develop plans for ISTC's participation in future ADR activities
  - ISTC provides a good potential mechanism for Russian contributions
- **1st European Workshop on Active Debris Removal**
  - A one-day event hosted by CNES in Paris in June 2010
  - Included more than 100 participants
  - Solidified CNES' plan to move forward with an ADR demonstration mission
- **International Academy of Astronautics**
  - Is conducting a study to survey existing ADR technologies (led by ESA and NASA

Other Major Events (2/2)

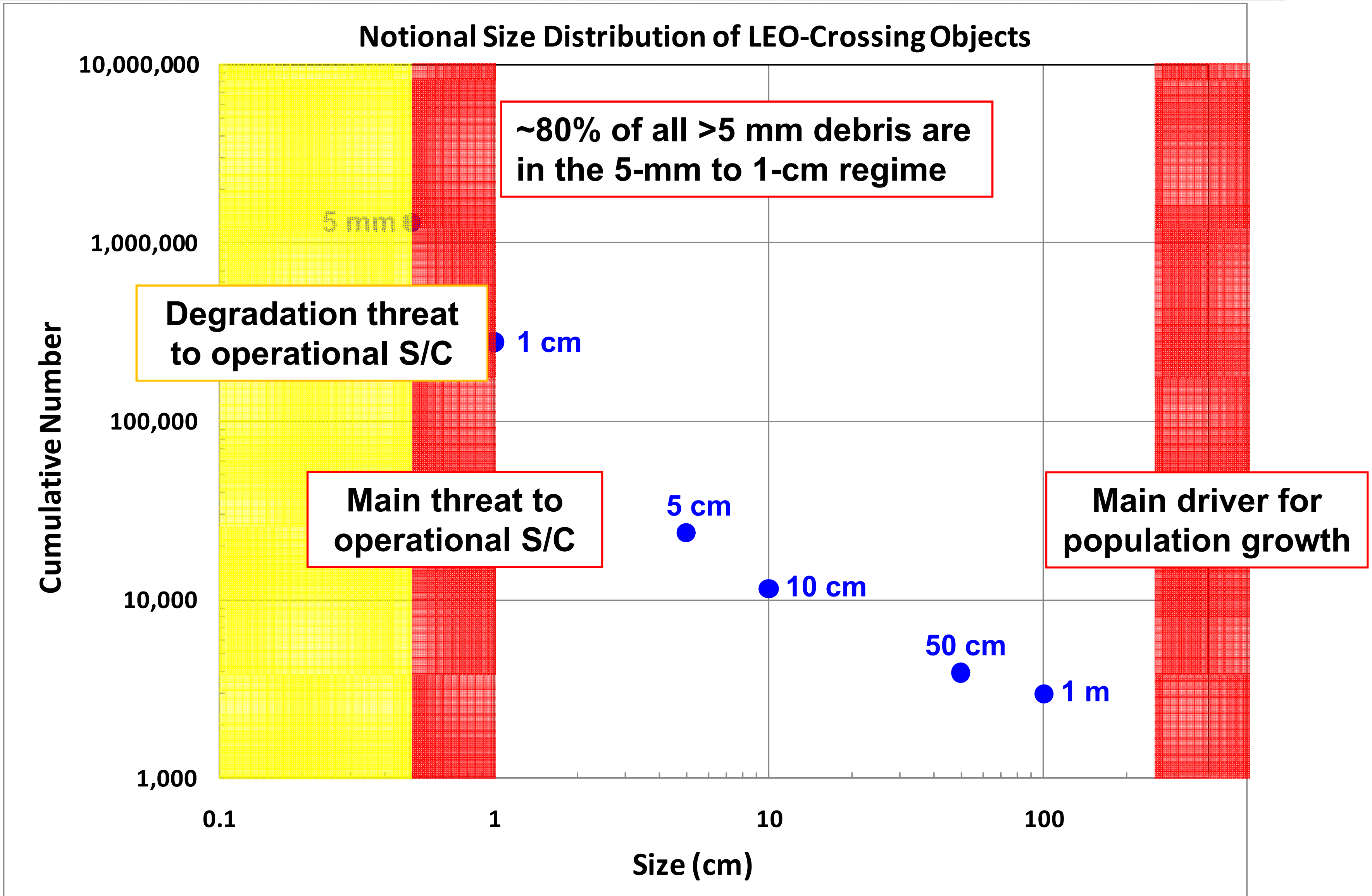
- **Inter-Agency Space Debris Coordination Committee (IADC)**
  - Is investigating the LEO environment instability problem
- **UN's Committee on the Peaceful Uses of Outer Space (COPUOS)**
  - Established a working group on the "long-term sustainability of outer space activities" in 2010
- **ADR sessions have been scheduled at AIAA, COSPAR, EUCASS, IAC, ISTS, and other international conferences**
- **2nd European Workshop on Active Debris Removal**
  - To be hosted by CNES in Paris on 18-19 June 2012

Summary

Concluding Remarks (1/4)

- **The LEO debris population will continue to increase even with a good implementation of the commonly-adopted mitigation measures**
  - The increase is driven by catastrophic collisions involving large and massive intacts
  - The major mission-ending risks for most operational satellites, however, come from impacts with debris just above the threshold of the protection shields (~5 mm to 1 cm)

Concluding Remarks (2/4)



Concluding Remarks (3/4)

- **To address the root cause of the population growth (for large <u>and</u> small debris)**

  → Target objects with the highest [M × P_{coll}]

  – To maintain the future LEO debris population at a level similar to the current environment requires an ADR of ~5 massive intacts per year

- **To address the main threat to operational satellites**

  → Target objects in the 5-mm-to-1-cm regime

  – The small debris environment is highly dynamic and will require a long-term operation to achieve the objective

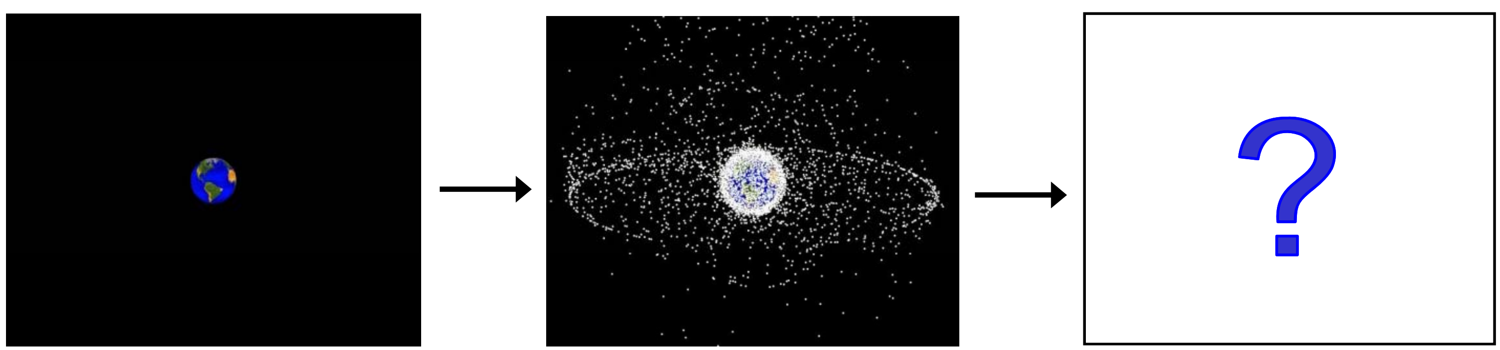
- **Targeting anything else will NOT be the most effective means to remediate the environment nor to mitigate risks to operational satellites**

Concluding Remarks (4/4)

- **There is a need for a top-level, long-term strategic plan for environment remediation**
  - Define "what is acceptable"
  - Define the mission objectives
  - Establish a roadmap/timeframe to move forward
- **The community must commit the necessary resources to support the development of low-cost and viable removal technologies**
  - Encourage dual-use technologies
- **Address non-technical issues, such as policy, coordination, ownership, legal, and liability at the <u>national and international</u> levels**

Preserving the Environment for Future Generations

- **Four Essential “Cs” are needed at the international level**
  - Consensus
  - Cooperation
  - Collaboration
  - Contributions



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Questions?